INDO-PACIFIC INFLUENCES IN AUSTRALIAN TERTIARY FORAMINIFERAL ASSEMBLAGES(1)

By Irene Crespin

[Read 10 June 1948]

I. INTRODUCTION

A recent examination of the microfaunal content of samples from numerous bores drilled in the Adelaide Plains by the Department of Mines, South Australia, has revealed some interesting information about the palaeogeography and stratigraphy of Tertiary sediments in Australia. Certain foraminiferal assemblages and zonal foraminiferal species have been discovered in the Tertiary sub-surface deposits in the Adelaide Basin which indicate an extension to Southern Australia of Indo-Pacific conditions in Upper Middle Miocene and Lower Pliocene times.

The work upon which the writer has been engaged in recent years has involved investigation of foraminiferal faunas of Tertiary deposits not only in Australia but in New Guinea, Papua, Timor, Java and Sumatra. With the discovery of Indo-Pacific assemblages in the sediments in the Adelaide Basin, time seems opportune to consider some observations that have been made and to attempt a correlation of the Australian deposits with those in the Indo-Pacific Region.

Perhaps the most striking observation is the very large area over which the same foraminiferal assemblages and even the rock types are to be found in the Region. The area extends from Japan south through the Philippines and Sumatra, east through Java, the smaller islands of the Netherlands East Indies, New Guinea, Papua, the Solomons and New Hebrides, and north to islands such as Guam. From Timor it extends south to north-western Australia, and from there across southern Western Australia to South Australia and north-western Victoria.

Early in these investigations it was realised that eastern Australian Tertiary and Recent faunas were very slightly influenced by the climatic and bathymetric conditions that prevailed in the Indo-Pacific Region from Tertiary times onward, and it is intended in this paper to indicate the limits of such influence, as indicated by the distribution of the larger foraminifera.

The sources from which information regarding the distribution of the larger foraminifera in the Australian Tertiaries has been drawn, are rock collections which have been made during reconnaissance surveys by geologists attached to various companies in their search for oil in the North-West Basin of Western Australia, and by geologists of the Commonwealth Bureau of Mineral Resources from the Nullarbor Plains and Eucla sections in Western and South Australia, as well as samples from bores which have been drilled for water in the Adelaide metropolitan area by the South Australian Department of Mines, and in the Mallee and Wimmera areas in north-western and central western Victoria by the State Rivers and Water Supply Commission.

II. PUBLISHED AND UNPUBLISHED SOURCES OF INFORMATION

Little published work is available on the problem of the stratigraphic position of the Tertiary foraminiferal rocks in Australia and their relationship with Indo-Pacific stratigraphy.

Howchin (889) recorded *Lepidocyclina* under the name of *Orbitolites* from the limestones at Clifton Bank near Hamilton, Victoria.

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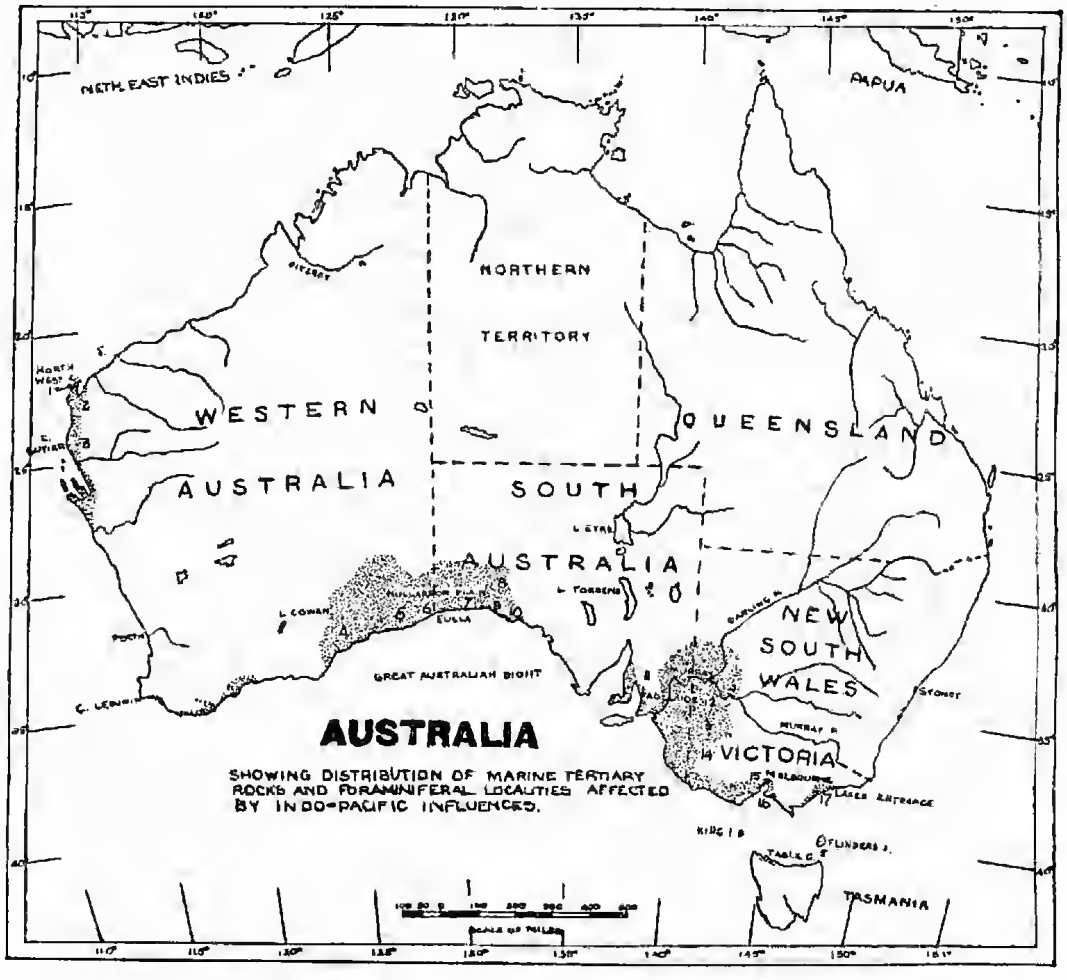
(1) Published by permission of the Director of the Bureau of Mineral Resources, Geology and Geophysics, Department of Supply and Development. Based on a paper read before Section C of the A.N.Z.A.A.S, Perth, August 1947.



Chapman (1910), in his study of the Batesford limestone, referred the *Lepidocyclinae* to European species, and Crespin (1926) listed *Ledipocyclina* from a limestone at Green Gully, near Keilor, Victoria.

The first record of larger foraminifera in north-west Australia was made by Chapman (1927), when he determined *Lepidocyclina dilatata* in a limestone submitted to him by F. G. Clapp from Exmouth Gulf. Later, in 1935, Chapman and Crespin determined Eocene foraminifera from rocks from the Giralia-Bullara area, North-West Division, Western Australia, collected by Messrs. Rudd and Condit. Species of *Discocyclina, Asterocyclina* and *Pellatispira* were recorded. In 1932 these two workers described *Lepidocyclinae* from bores in the Tertiary rocks of Victoria and suggested a correlation (based on the determination of *Spiroclypeus* in a limestone from Hamilton) of these deposits with "Stage e" in Java. Crespin later (1936) considered the specimen to be a section of a test of *Lepidocyclina*.

Raggatt (1936) included a short account based on departmental reports by Chapman and Crespin, of the Tertiary rocks of the North-West Basin, Western Australia, in his geology of the area.

In a report to the Australian and New Zealand Association for the Advancement of Science in Auckland (1937), the writer summarised the occurrences of Tertiary marine rocks in north-west Australia and indicated their relationships with Indo-Pacific types, and at the same time Chapman reported on the discovery of Eocene rocks in that area.

Crespin (1936) discussed the larger foraminifera in the Tertiary rocks of Victoria which were referred to the Lower Miocene, and suggested that the subgenus *Lepidocyclina* indicated a younger age for the beds. Later, in 1941 and 1942, she made detailed studies of the genera *Cycloclypeus* and *Lepidocyclina* respectively in the Tertiary of Victoria and indicated their position in the Indo-Pacific stratigraphy. The subject was discussed further in her work on the Tertiary deposits of Gippsland, Victoria (1943).

Glaessner (1943) brought up to date the various lines of thought regarding Indo-Pacific Tertiary stratigraphy in his "Problems of Stratigraphic Correlation in the Indo-Pacific Region." Australia received little attention by Glaessner because of lack of published work.

Information on the foraminiferal assemblages in South Australian Tertiary deposits was derived from Howchin and Parr's study of the foraminifera in the metropolitan Abattoirs Bore, Adelaide (1938), and from Howchin's work on other bores in 1935 and 1936. Chapman's report (1916) on the Mallee Bores in Victoria formed the basis for work in that area and in the Wimmera.

Considerable evidence has been derived from unpublished departmental palaeontological reports since 1934, and these may be discussed under two headings: (a) North-West Basin, Western Australia, and (b) Southern Western Australia, South Australia and north-western Victoria.

(a) North-West Basin, Western Australia

Information has been derived from rock collections made by geologists during reconnaissance surveys for various companies engaged in the search for oil.

In 1934 D. Dale Condit and E. A. Rudd, on behalf of Oil Search Ltd., investigated the Exmouth Gulf area and collected limestones containing typical Eocene and Miocene Indo-Pacific foraminifera. H. G. Raggatt carried out further work for Oil Search Ltd. in this area in 1934, and in 1935 he was accompanied by Washington Gray of the Commonwealth Oil Refineries Ltd. Both geologists made large collections of fossiliferous material. In 1936 E. A. Rudd made a further reconnaissance of the Exmouth Gulf area for Oil Search Ltd. and extended his survey down to the coastal section at Red Bluff and Cape Cuvier, and in 1941 geologists attached to Caltex (Australia) Oil Development, visited the Exmouth Gulf area and made collections from sections in Rough Range and Cape Range area.

(b) Southern Western Australia, South Australia and North-western Victoria

The greater part of the information on this region has been derived from bores drilled for water in South Australia and north-western Victoria, and from collections of fossiliferous limestones made by geologists of the Bureau of Mineral Resources, Canberra, and students of the University of Adelaide. The State Rivers and Water Supply Commission of Victoria has lately been drilling for water in the Wimmera, and since 1908 has had a drilling programme in the Mallee.

In 1944, H. B. Owen of the Bureau of Mineral Resources accompanied a party of geophysicists of the same organisation on a trip along the coastline of the Great Australian Bight from Port Lincoln in South Australia to Eyre in

Western Australia, and then across to Booanya and Balladonia. Owen collected from all available limestone outcrops between Ceduna and Norseman and made geological observations in this Tertiary Basin.

Last year Mr. King, a student of the Department of Geology, University of Adelaide, explored caves on the Nullarbor Plains and collected rocks from various localities in the vicinity of the caves.

Limestones have also been examined by the writer from Cook and Ooldea on the Transcontinental Railway.

III. METHOD OF CORRELATION OF TERTIARY MARINE ROCKS IN THE INDO-PACIFIC REGION

The basis of correlation of the Tertiary marine rocks in the Indo-Pacific Region is the distribution of the larger foraminifera in them. Dutch palaeontologists found it difficult to recognise some of the European stages in the Indo-Pacific, and in 1927 Van der Vlerk and Umbgrove instituted a "letter" classification. Since that time a considerable amount of detailed work has been carried out on the Tertiary faunas in the Netherlands East Indies by Dutch palaeontologists in collaboration with field geologists, with the result that a convenient classification was put forward by the late Dr. Tan Sin Hok in 1939, and this can be applied readily to those Tertiary rocks in Australia which come under the influence of Indo-Pacific conditions at the time of deposition. Tan's scheme, which has been modified by Glaessner (1943), is as follows:

Neogene	Upper Neogene (formerly "g" - "h")
	Upper Middle Neogene ("f_3")
	Lower Middle Neogene ("f_1" - "f_2")
	(Lower Neogene (Aquitanian, "e", included in Miocene)
Palaeogene	Oligocene ("c" - "d", distinguishable from Aquitanian only if reticulate Nummulites present)
	Eocene ("a" - "b")

This scheme is further modified in its application to Australia. It is considered that the following close approximations can be made—the Lower Neogene to the Lower Miocene, the Middle Neogene to the Middle to Upper Miocene, and the Upper Neogene to the Pliocene.

Characteristic larger foraminifera for the stages are:

Pliocene	Absence of larger zonal foraminifera
Upper Miocene ("f_3")	*Trybliolepidina rutteni*
Middle Miocene ("f_1" - "f_2")	*Nephrolepidina, Miogypsina, Flosculinella, Cycloclypeus, Austrotrillina*
Lower Miocene ("e")	*Eulepidina, Spiroclypeus, Neoalveolina*
Oligocene ("c" - "d")	*Eulepidina* and reticulate *Nummulites*
Eocene ("a" - "b")	*Assilina, Nummulites, Pellatispira, Discocyclina, Asterocyclina, Actinocyclina*

Rocks containing typical Eocene ("a" - "b"), Oligocene ("c" - "d") and Lower Miocene ("e") larger foraminifera are found only in north-western Australia. Zonal foraminifera of "f stage" are widely distributed not only in rocks in the North-West Basin but on the Nullarbor Plains and in the Eucla Basin, and in bores in the Adelaide Plains and north-western Victoria. Typical "f_3" rocks

with *Tryblio1epidina rutteni* have not yet been found. Pliocene deposits probably equivalent to "g" occur along the north-western coast, on the Nullarbor Plains, and in the Adelaide Basin.

IV. APPLICATION OF THE "LETTER" CLASSIFICATION TO AUSTRALIAN MARINE TERTIARY DEPOSITS

Localities from which typical zonal foraminifera of the Indo-Pacific Region have been recorded in Australia are listed in Table I, which also gives the stratigraphic position of the various deposits.

A. Eocene ("a" - "b")

The only localities in Australia from which "a"-"b" foraminifera have been recorded are Giralia and Bullara south of the head of Exmouth Gulf, and at Red Bluff and Cape Cuvier in the coastal section south of the Exmouth Gulf area in the North-West Basin, Western Australia. Species of *Discocyclina, Asterocyclina, Actinocyclina, Pellatispira* and *Nummulites* have been determined. The exact position of these beds in the Eocene stratigraphic sequence is uncertain. *Pellatispira* and *Discocyclina* disappear at the top of the Eocene.

B. Oligocene ("c" - "d")

Definite Oligocene limestones are also restricted to the North West Basin of Western Australia. Large species of *Eulepidina* (*E. dilatata, E. papuaensis*) large *Cycloclypeus* (*C. eidae*) and small reticulate nummulites occur in the limestones from the base of an open gorge north of Mount King, Cape Range, and from the base of the section at Badjirrajirra Creek (north fork) 4·7 miles from its mouth on the Exmouth Gulf side of Cape Range. Chapman recorded *E. dilatata* from Exmouth limestones in 1927. He described *E. papuaensis* from a limestone at Bootless Inlet, Papua (1914), which contained small nummulites (*N. intermedia*) and which is now considered to be of Oligocene age.

C. Lower Miocene ("e")

Similarly, limestones containing typical Lower Miocene zonal foraminifera have not been found south of the North-West Basin. *Eulepidines* typical of stage "e" (*E. insulaenatalis, E. papuaensis*) are present in limestone 22 miles south of Yardie Creek Station, Cape Range. Other zonal forms, *Spiroclypeus tidoenganensis* and *Neoalveolina pygmaea*, together with small *Nephrolepidina* occur in rocks from Rough Range near Exmouth Gulf Homestead. *Eulepindina, Spiroclypeus* and *Neoalveolina* are not known to range above the top of "stage e".

D. Middle to Upper Miocene ("f")

Rocks of "stage f" are widely distributed in the North-West Basin and occur as far south as the section across southern Australia from Booanya and Balladonia in Western Australia to Colona east of the head of the Great Australian Bight in South Australia, thence to near Adelaide and across to north-western Victoria. No typical "f_2" rocks have been found. It is more satisfactory to subdivide the "stage f" rocks in Australia into "f_1 - f_2" and "f_2 - f_3". Probably some of the limestones in the Badjirrajirra Creek section may be referable to "f_1", but "f_3" has not yet been recorded.

"f_1 - f_2" rocks contain two assemblages of zonal foraminifera:

(2) An upper one with *Nephrolepidina* with some species showing *Tryblio-lepidina* tendencies, *Flosculinella, Cycloclypeus* and *Miogypsina*.

(1) A lower one with *Nephrolepidina* and *Cycloclypeus*.

Limestones containing Assemblage 1 occur in the Badjirrajirra Creek section, *Cycloclypeus* being the dominant form. This rock may be referable to "f_1". Well preserved specimens of the echinoid *Conoclypeus* were found in these beds.

Assemblage 2 shows an intermingling of typical "f_1" and "f_2" species and is fairly widely distributed in limestones in the Cape Range and Rough Range sections.

"f_2 - f_3" rocks have a wide distribution in Australia, and two assemblages of foraminifera are recognisable in them:

(1) Without *Lepidocyclina* but with *Austrotrillina, Flosculinella, Marginopora, Valvulina, Sorites, Peneroplis* and Miliolidae.

(2) With *Lepidocyclina*, also *Flosculinella, Marginopora* and Miliolidae.

It is possible that these two assemblages are equivalent in age, the absence of *Lepidocyclina* in Assemblage 1 being due to change in facies rather than difference in age.

Assemblage 2 is recorded from only two localities, one at Exmouth Gulf Station Outcamp in Rough Range, and the other near Yardie Creek Homestead, Cape Range in the North-West Basin. The assemblage is well known in the limestones in New Guinea and Papua and in parts of the Netherlands East Indies.

Assemblage 1 occurs in rocks in widely separated areas, from the North-West Basin, Western Australia, through the Nullarbor Plains to South Australia, thence to north-western Victoria, the same rock type ocurring from North-West Basin to the Nullarbor Plains. The limestone is cryptocrystalline, the foraminifera tests usually being stained black. The assemblage occurs in friable limestones in bores in the Adelaide Plains and in the Mallee and Wimmera in north-western Victoria.

Rocks containing Indo-Pacific Pliocene assemblages are not common in the Australian Tertiaries. Some of the coralline limestones in the Yardie Creek area, North-West Basin, have been placed in the Pliocene but no foraminifera are available to confirm this.

The limestones near Minilya Station, North-West Basin, contain *Marginopora, Sorites, Peneroplis* and *Valvulina* and in the absence of zonal Miocene forms are referred to the Pliocene. An identical rock, both in lithology and faunal content, occurs at Ooldea on the Nullarbor Plains and in the vicinity of Weebabbie Caves near Eucla. Numerous casts of molluscan shells, referable to species recorded from the Adelaide Plains deposits are present in the rock.

In the vicinity of Adelaide, extensive fossiliferous deposits known as the "Adelaidean" underlie the Adelaide Plains and outcrop at Hallett's Cove, at Christie's Beach, Port Noarlunga and at Aldinga. The foraminifera genera *Marginopora, Sorites, Peneroplis* and *Valvulina* form a characteristic assemblage, but the occurrence of zonal species of the Kalimnan stage of Victoria indicate a Lower Pliocene age for the beds.

V. COMMENTS ON THE INDO-PACIFIC ZONAL FORAMINIFERA IN AUSTRALIAN TERTIARY DEPOSITS

The zonal foraminifera in the Eocene ("a - b"), Oligocene ("c - d") and Lower Miocene ("e") rocks call for little comment. All species that have been determined are characteristic of the deposits of these ages throughout the Indo-Pacific, from Japan, the Philippines, Netherlands East Indies, New Guinea, Papua and north-western Australia, but are not known from southern Australia. However, in the Middle to Upper Miocene rocks which do extend to southern Australia, several species of zonal importance throughout the Indo-Pacific not only occur there but were described from the area.

The most important zonal form used in the correlation of "f stage" rocks is *Lepidocyclina* with its two subgenera *Nephrolepidina* and *Trybliolepidina*. The genus is found in the North-West Basin of Western Australia, but has not yet been recorded from limestones on the Nullarbor Plains nor in the vicinity of Adelaide and north-western Victoria, but it does occur in western, central southern and south-eastern Victoria. The subgenera *Nephrolepidina* is the zonal form for "f_1 - f_2" beds and it has not been recorded south of Cape Cuvier. Similarly, *Miogypsina*, which is characteristic of the "f_1 - f_2" assemblage, has not been found south of the North-West Basin.

In "f_2 - f_3" beds, *Nephrolepidina* gradually gives way to *Trybliolepidina*, which is very common at this horizon in the Indo-Pacific. On the Nullarbor Plains, from Booanya in Western Australia to Colona in South Australia, thence to the Adelaide Bores and Mallee and Wimmera Bores, *Trybliolepidina* is replaced by an assemblage in which the most important zonal form is *Austrotrillina howchini*. The associated zonal genus *Flosculinella* does not occur east of Colona.

Austrotrillina howchini, of such importance in "f stage" foraminiferal faunas in the Indo-Pacific, was described by Schlumberger (1893) from *Lepidocyclina* limestones at Clifton Bank, near Hamilton, western Victoria. The species has been recorded from "e stage" but has its greatest development in "f stage". The age of the beds from which *A. howchini* was described has been based on the *Lepidocyclina* population, which is dominated by the subgenus *Trybliolepidina* and which is regarded as the equivalent of "f_2 - f_3", and somewhere about the boundary of the Burdigalian and Vindobonian of the European stages (Crespin, 1942). Records indicate that *A. howchini* has not been found in the Indo-Pacific Region outside Australia in rocks younger than "f_2".

Other species which have been described from the Victorian *Lepidocyclina* limestones and which are found as far north as the North-West Basin in Western Australia, are *Gypsina howchini*, *Planorbulinella plana*, and *P. inaequilateralis*. Two other zonal species, *Crespinella umbonifera* and *Calcarina verriculata*, were described from bores in the Adelaide Basin from the *Austrotrillina howchini* horizon (Howchin and Parr, 1938). *C. verriculata* is very common in the *Lepidocyclina* limestones at Batesford. Both species are found in the North-West Basin.

An interesting assemblage of recent warm water genera, *Marginopora*, *Sorites*, *Peneroplis*, Miliolidae, occurs in the "f_2 - f_3" rocks and in the Pliocene in that portion of the Australian Tertiaries which have been subjected to Indo-Pacific influences at the time of deposition. This assemblage is found in rocks of topmost Miocene to Recent age throughout the Indo-Pacific, age being determined by the presence of zonal foraminifera. It is associated with *Austrotrillina* in "f_2 - f_3" limestones at Cape Cuvier in north-western Australia, in some of the limestones on the Nullarbor Plains, and in bores in the Adelaide Plains and in the Mallee and Wimmera. *Marginopora* rarely occurs in association with *Lepidocyclina*, due apparently to the fondness of the former genus for quiet tropical waters such as are found in the proximity of coral reefs. *Lepidocyclina* is usually associated with bryozoa which thrive where currents are present. The *Marginopora-Sorites-Peneroplis*-Miliolidae assemblage occurs with zonal Lower Pliocene (Kalimnan) species in the "Adelaidean" of the Adelaide Basin.

VI. POSITION OF THE MIDDLE TO UPPER MIOCENE AND PLIOCENE DEPOSITS OF SOUTHERN VICTORIA IN THE INDO-PACIFIC "LETTER" CLASSIFICATION

Broadly speaking, the majority of the bryozoal limestones in the Tertiary deposits of southern Victoria can be correlated with "f_2 - f_3" stage", based on

the presence of *Trybliolepidina* in the upper portion of the section. The writer, in her investigations on the genera *Lepidocyclina* and *Cycloclypeus* in Victoria (1941, 1942), showed that the subgenus to which the *Lepidocyclina* belonged was *Trybliolepidina*, and that the species of these two genera were different from those in known Indo-Pacific deposits. She suggested that this difference in species was due to "the presence of an embayment in south-eastern Australia in which other species, but still with Indo-Pacific affinities, flourished." Glaessner (1943) sums up the problem in the following statement: "Faunal relations between the surprisingly uniform Tertiary of the Indo-Pacific Region and that of south-eastern Australia and New Zealand are limited and are either created by "eurythermic" species which were able to cross the boundary of the tropical belt or by short-lived climatic or ecologic changes, creating a suitable environment for warm-water species and genera. In the Tertiary of Victoria the Batesfordian, containing a group of *Lepidocyclina* as well as *Austrotrillina* and perhaps some other Indo-Pacific smaller foraminifera, forms a short-lived link with the Indo-Pacific Region."

Although *Austrorillina howchini* was described from the *Lepidocyclina* limestone at Clifton Bank near Hamilton, it is not a common form in the *Lepidocyclina* deposits in southern Victoria. It does not occur in the rich *Lepidocyclina* limestones at Batesford and Flinders in the central southern portion, nor in Brock's Quarry and in the numerous bores from which the *Lepidocyclina* horizon has been recorded in Gippsland, but it does occur sparingly in that horizon at Skinner's section, Mitchell River, near Bairnsdale, Gippsland. The species is well represented in the portion of the Mallee Bores which have been subjected to Indo-Pacific influence and where it is associated with *Marginopora*. The typical Indo-Pacific genera *Miogypsina* and *Flosculinella* have not been recorded from Victoria.

The Middle Miocene bryozoal limestones of south-eastern South Australia and western Victoria contain no large zonal foraminifera, but some of the limestones are correlated with the "f_2 - f_3" beds of Victoria by means of smaller zonal species which are associated with the larger forms in the *Lepidocyclina* limestones.

No zonal Indo-Pacific foraminifera are known from the Victorian Lower Pliocene—referred to as the Kalimnan—which suggests unsuitable ecologic conditions during Pliocene times in Victoria. According to present knowledge, suitable conditions did not extend eastward beyond the vicinity of Adelaide.

VII. SUMMARY

1. Indo-Pacific influence in faunal assemblages in Australian Tertiary rocks extends from North-West Basin, Western Australia, to southern Western Australia, across the Nullarbor Plains to South Australia and north-western Victoria.

2. Correlation of the marine Tertiaries of Australia with occurrences elsewhere in the Indo-Pacific Region is made by means of the larger foraminifera, which form the basis of the letter classification instituted by Dutch palaeontologists in their work in the Netherlands East Indies.

3. Eocene ("a - b"), Oligocene ("c - d") and Lower Miocene ("e") rocks containing typical zonal foraminifera are not recorded south of the North-West Basin, Western Australia.

4. Middle to Upper Miocene ("f") zonal foraminifera are widely distributed in limestones in southern Western Australia, across the Nullarbor Plains, in the vicinity of Adelaide and in north-western Victoria. Even similar rock types have been recognised.

5. No larger zonal foraminifera of age value are present in the rocks of Pliocene age, local zonal species being age determinants. But associated with the local species are well-known Indo-Pacific recent forms. Rocks containing such assemblages occur in the North-West Basin, at Ooldea on the Nullarbor Plains and in the Adelaide Bore sections and in the coastal sections south of Adelaide, where they are referred to as the "Adelaidean" and are Lower Pliocene.

6. The *Lepidocyclina* limestones of Victoria, which are considered to be equivalent to "f_2 - f_3" stage indicate a short-lived link with the Indo-Pacific. The genus *Lepidocyclina*, which is represented by the subgenus *Trybliolepidina*, shows Indo-Pacific affinities, but the species are distinct.

7. The conclusion drawn from the above observations is that Indo-Pacific conditions extended down the coast of Western Australia, across the southern part of the State into South Australia and north-western Victoria in Middle Miocene to early Upper Miocene ("f_2 - f_3") time, with a very limited extension into southern Victoria. Then followed a gradual recession of conditions. No Pliocene deposits containing Indo-Pacific forms are known east of the Adelaide Plains and the sections south of Adelaide along Gulf St. Vincent. According to Cotton, of the South Australian Museum, the examination of molluscan faunas in South Australia suggests that this recession has continued westwards during Pleistocene and Recent times.

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